

The FMS Exchange Grid: a mechanism for data exchange between Earth System components on independent grids

GFDL-NCAR Atmospheric GCM Meeting

V. Balaji¹ Jeff Anderson² Isaac Held³ Mike Winton³
Sergey Malyshev¹ Ron Stouffer³

¹Princeton University

²NCAR

²NOAA/GFDL

8 May 2007

1 The FMS Coupler

- FMS Coupler Overview
- FMS Coupler: Serial and concurrent modes in one executable

2 The Exchange Grid

- FMS Coupled Architecture
- FMS Coupler: implicit coupling
- FMS Coupler: flux exchange on independent grids
- The exchange grid and the land-sea mask

1 The FMS Coupler

- FMS Coupler Overview
- FMS Coupler: Serial and concurrent modes in one executable

2 The Exchange Grid

- FMS Coupled Architecture
- FMS Coupler: implicit coupling
- FMS Coupler: flux exchange on independent grids
- The exchange grid and the land-sea mask

The FMS coupler

Used for data exchange between models. Key features include:

Conservation: required for long runs.

Resolution: no constraints on component model timesteps and spatial grid. Supports both explicit and implicit timestepping.

Exchange grid: union of component model grids, where detailed flux computations are performed (Monin-Obukhov, tridiagonal solver for implicit diffusion, ...)

Fully parallel: Calls are entirely processor-local: exchange software will perform all inter-processor communication.

Single executable: serial and concurrent execution in a single executable.

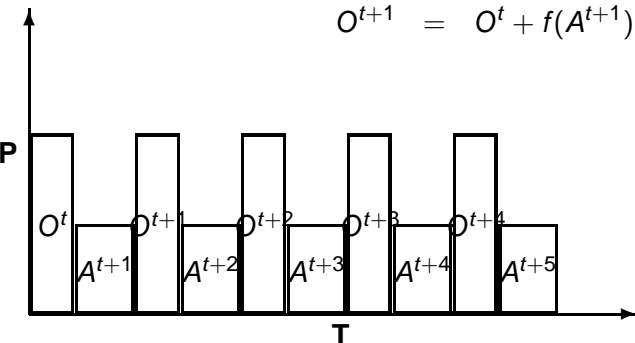
Highly efficient: currently able to couple atmos/ocean explicitly at each ocean timestep, atmos/land/ice implicitly at each atmos timestep for current dec/cen models.

Serial coupling

Uses a forward-backward timestep for coupling.

$$A^{t+1} = A^t + f(O^t) \quad (1)$$

$$O^{t+1} = O^t + f(A^{t+1}) \quad (2)$$

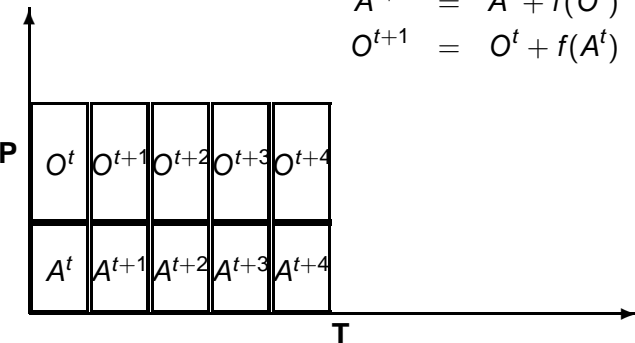


Concurrent coupling

This uses a forward-only timestep for coupling. While formally this is unconditionally unstable, the system is strongly damped. Answers vary with respect to serial coupling, as the ocean is now forced by atmospheric state from Δt ago.

$$A^{t+1} = A^t + f(O^t) \quad (3)$$

$$O^{t+1} = O^t + f(A^t) \quad (4)$$



1 The FMS Coupler

- FMS Coupler Overview
- FMS Coupler: Serial and concurrent modes in one executable

2 The Exchange Grid

- FMS Coupled Architecture
- FMS Coupler: implicit coupling
- FMS Coupler: flux exchange on independent grids
- The exchange grid and the land-sea mask

Implicit coupling and the exchange grid

Fluxes at the surface often need to be treated using an implicit timestep. (e.g temperature flux in near-surface layers that can have vanishingly small heat capacity.)

$$\frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial z^2} \quad (5)$$

$$\frac{T_k^{n+1} - T_k^n}{\Delta t} = K \frac{T_{k+1}^{n+1} + T_{k-1}^{n+1} - 2T_k^{n+1}}{\Delta z^2} \quad (6)$$

$$\mathbf{A}\mathbf{T}^{n+1} = \mathbf{T}^n \quad (7)$$

Implicit coupling and the exchange grid

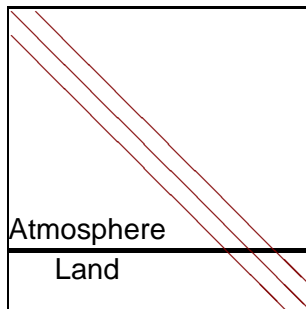
Atmosphere



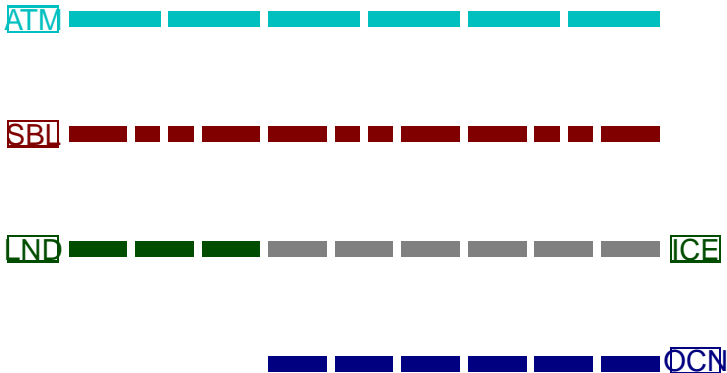
Exchange



Land



FMS coupled architecture



Flux exchange

Three types of flux exchange are permitted: REGRID, REDIST and DIRECT.

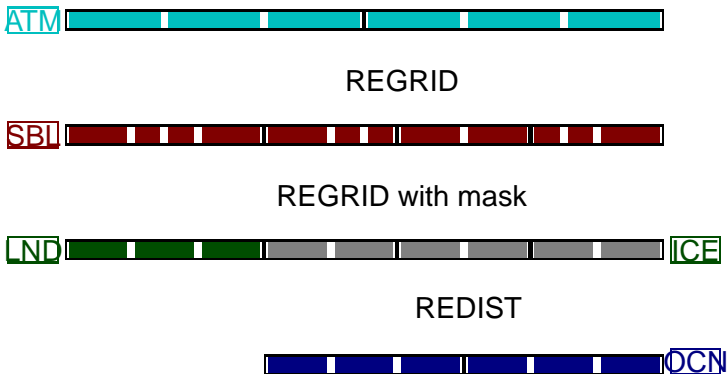
REGRID physically distinct grids, requires exchange grid.

REDIST identical global grid, different domain decomposition.

DIRECT identical grid and decomposition.

Current use: REGRID between $\text{atmos} \longleftrightarrow \text{ice}$, $\text{atmos} \longleftrightarrow \text{land}$, $\text{land} \longleftrightarrow \text{ice}$, REDIST between $\text{ocean} \longleftrightarrow \text{ice}$.

FMS coupled architecture: parallelism



Exchange grid: features

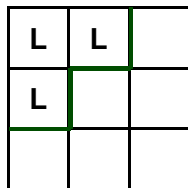
- Each cell on exchange grid “belongs” to one cell on each parent grid;
- Conservative interpolation up to second order;
- All calls exchange local data; data-sharing among processors is internal to the exchange software, and non-blocking.
- Physically identical grids (e.g ocean and sea ice) exchange data without interpolation.
- Exchange grid is computed and stored offline following a homegrown netCDF “standard”.

Exchange grid size

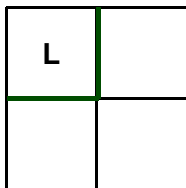
Atmosphere	Ocean	Xgrid	Density	Scalability
144×90	360×200	79644	8.5×10^{-5}	0.29
288×180	1080×840	895390	1.9×10^{-5}	0.56

Exchange grid sizes for typical climate model grids. The first column shows the horizontal discretization of an atmospheric model at “typical” climate resolutions of 2° and 1° respectively. The `ocean` column shows the same for an ocean model, at 1° and $\frac{1}{3}^\circ$. The `xgrid` column shows the number of points in the computed exchange grid, and the density relates that to the theoretical maximum number of exchange grid cells. The `scalability` column shows the load imbalance of the exchange grid relative to the overall model when it inherits its parallel decomposition from one of the parent grids.

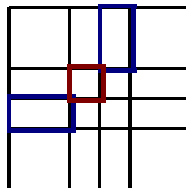
The mask problem



Land



Ocean



Exchange

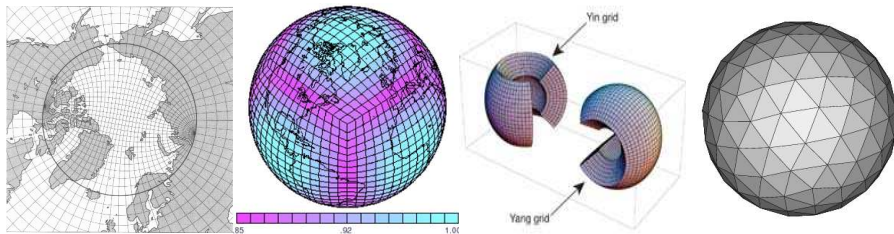
An issue arises when grids of two independent components (e.g land and sea) share a boundary. The boundary is defined by a **mask** (e.g land-sea mask) but the mask is discretized independently on the two grids. However, exchange grid cells need to be uniquely assigned to a single component. This means that some cells get **clipped** on one or the other grid. In FMS, by convention, we choose to clip the land grid.

Cubed-sphere issues

The fundamentals of the exchange grid do not change as we move to the cubed sphere grid. However, there are some software issues that are nearing resolution.

- Exchange grid generation was optimized using an assumption that one of the parent grids was a lon-lat grid. This is now violated.
- The grid specification standard has changed to accommodate grid *mosaics*.
<http://www.gfdl.noaa.gov/~vb/gridstd/gridstd.pdf>
- As Isaac noted this morning, there is still an open question about the amplitude of implicit horizontal diffusion due to the exchange grid.

Mosaic grid specification



Exchange grid: literature

- Balaji *et al* 2006: “The FMS Exchange Grid: a mechanism for data exchange between Earth System components on independent grids”:

<http://www.gfdl.noaa.gov/~vb/pdf/xgridpaper.pdf>

- Isaac Held's notes: “Surface Fluxes, Implicit Time Stepping, and the Exchange Grid: The Structure of the Surface Exchange Module” <http://www.gfdl.noaa.gov/~vb/pdf/surf.pdf>